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CHROMITE: ITS MINERAL AND CHEMICAL COMPOSITION¹

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INTRODUCTION

The mineral called chromite is a member of the spinellid group of minerals which crystallize in the isometric system. The spinellids have the general formula $R''O \cdot R'''_2O_3$. Chromite, however, is seldom found as a pure double oxide. Replacement of FeO by MgO and Cr_2O_3 by either or both Al_2O_3 and Fe_2O_3 gives rise to varietal types and chief among these are chrompicotite, chromhercynite, magnesiochromite (mitchellite), picotite and chromiferous spinels. The mineral called chromite can seldom be expressed by a definite formula. It is usually a mixture of the varietal types cited. There is a strong probability that the spinellids, magnetite, magnesioferrite and others enter into its chemical makeup.

The spinellids have been classified by various investigators and it is not necessary to go into the details of subdivision of the group. There are four major sub-groups: the aluminates, chromates, manganates and ferrates, represented by spinel, chromite, jacobsite and magnetite, respectively

The physical properties of chromite are, briefly stated: lustrous to pitchy black color, fine grained granular to crystallized octahedra, rarely truncated by the cube or beveled by the rhombic dodecahedron; M.W. 223.84; S.G. 4.32-4.57; M.V. 50.3; $n = 2.07$ to 2.16; fusibility 2180°C.

STUDY OF THE PUBLISHED ANALYSES

More than 150 published analyses of supposed chromite have been collected in order to ascertain the formula of the mineral. Various lines of attack might be followed to gain this goal. Among these are:

¹ An abstract of a portion of a dissertation submitted to the Board of University Studies of the Johns Hopkins University in conformity with the requirements for the degree of Doctor of Philosophy.

- (1) Study of ratios between the bivalent and trivalent oxides.
- (2) Study of methods in which the various oxides are combined in the mineral.
- (3) Deduction of formula from individual analyses.
- (4) Calculation of ratios that exist between the various oxides listed in the analyses.

RATIOS

It has been suggested that the spinellids are double oxides and they may be represented by the general formula set forth above. A study of analyses indicates that the ratio of 1:1 between bivalent and trivalent oxides is not the general rule in the species chromite. No analysis of chromite shows the presence of zinc, and since chromite is considered to be an isomorphous mineral closely related to other spinellids, the absence of zinc eliminates relationship to zinciferous spinels.

An effort is first made to correlate ratios of the bivalent to trivalent oxides. This leads to the following result:

Ratio of $R_2'''O_3$ to $R''O$
(molal amounts)

	av.
Lowest ratio	1:0.53
"Subnormal" (less than 1:0.90)	1:0.774
"Normal" (between 1:0.90 and 1:1.00)	1:0.998
"Abnormal" (greater than 1:1.00)	1:1.340
Highest ratio	1:3.69

All the analyses termed "subnormal" and "normal" fall below the average of the entire number of analyses, namely, 1:1.13. The average ratio of the subnormal and normal groups is 1:0.934. The terms used in the above tabulation will be used throughout this discussion in the sense designated.

A comparison between the relative percentages of true spinels and chromite that fall within the three normality ranges is shown below.

	RATIOS					
	Lowest	Subnormal	Normal	Abnormal	Highest	Average
Spinel	1:0.64	1:0.707 (12.6%)	1:0.980 (76.7%)	1:1.23 (10.7%)	1:1.47	1:0.97
Chromite	1:0.53	1:0.774 (15.2%)	1:0.998 (38.3%)	1:1.34 (46.3%)	1:3.69	1:1.13

Note: average ratio of groups is given; per cent indicates total number of analyses represented that falls within group.

Ratios between the total bivalent and trivalent oxides reported in mineral analyses depend entirely on two features. First: It is necessary to reduce and eliminate, by some arbitrary method, oxides which do not enter into the composition of the spinellid. Second: Improper and incomplete methods of analyses are often causes of abnormal or subnormal ratios (*i.e.* such analyses are sometimes detected where all iron of chromite is reported as either all ferrous or all ferric). If all iron is determined as ferrous the mineral species will probably fall in the abnormal group.

From a comparison of the relative percentages of spinel and chromite that fall within the normal group it is noted that less than 40% of the chromite analyses are normal. In attempting to solve the reason for this, certain subtractions are made from the abnormal analyses. In a heavy gravity separation it is impossible to secure absolutely pure material for analysis, for chromite is often fractured and contains much serpentine, k  mmererite, and other hydrous minerals. Hence, water, carbon dioxide, silica, excess magnesia, etc., must be eliminated. Oxides have been subtracted on the following basis: Serpentine— $2\text{H}_2\text{O} \cdot 3\text{MgO} \cdot 2\text{SiO}_2$; Enstatite— $\text{MgO} \cdot \text{SiO}_2$; Magnesite— $\text{MgO} \cdot \text{CO}_2$; Uvarovite— $3\text{CaO} \cdot \text{Cr}_2\text{O}_3 \cdot 3\text{SiO}_2$; Ilmenite— $\text{FeO} \cdot \text{TiO}_2$; and Rutile— TiO_2 .

Titanium minerals are nearly restricted to those chromites which occur in chromiferous magnetites or in the chromiferous serpentines that carry rutile. In some of the analyses no oxides other than those really essential to the spinellid have been reported and such analyses allow no correction.

MUTUAL REPLACEMENT OF OXIDES

Another classification, purely chemical in nature, is suggested and is to be used in connection with the ratio classification. The various analyses of chromite are grouped according to their contained oxides and comparisons between such groupings are thus afforded. The collected analyses fall into the following chemical groups:

		No. of anal.	% of total
Type I.	$\text{FeO} \cdot \text{Cr}_2\text{O}_3$	3	2.0
"	IIa. $\text{FeO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Cr}_2\text{O}_3$	12	8.0
"	IIb. $\text{FeO} \cdot \text{Fe}_2\text{O}_3 \cdot \text{Cr}_2\text{O}_3$	1	0.6
"	IIc. $\text{FeO} \cdot \text{Fe}_2\text{O}_3 \cdot \text{Al}_2\text{O}_3 \cdot \text{Cr}_2\text{O}_3$	0	0.0
"	III. $\text{FeO} \cdot \text{MgO} \cdot \text{Cr}_2\text{O}_3$	2	1.2
"	IIIa. $\text{FeO} \cdot \text{MgO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Cr}_2\text{O}_3$	96	64.0

"	IIIb. $\text{FeO} \cdot \text{MgO} \cdot \text{Fe}_2\text{O}_3 \cdot \text{Cr}_2\text{O}_3$	0	0.0
"	IIIc. $\text{FeO} \cdot \text{MgO} \cdot \text{Fe}_2\text{O}_3 \cdot \text{Al}_2\text{O}_3 \cdot \text{Cr}_2\text{O}_3$	31	20.6
"	IIId. $\text{FeO} \cdot \text{MgO} \cdot \text{Mn}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3 \cdot \text{Al}_2\text{O}_3 \cdot \text{Cr}_2\text{O}_3$..	5	3.3
"	IV. $\text{MgO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Cr}_2\text{O}_3$	1	0.6

The most prominent types are IIa, IIIa and IIIc. The discussion will be based chiefly on these types and the nomenclature cited above will be used with that adopted for the ratios.

RELATED SPECIES

Many of the analyses of so-called chromites contain varying amounts of ferrous iron and magnesia. Varietal types arise because of such replacements. The common varietal species of chromite are:

	Al_2O_3	Cr_2O_3	FeO	MgO	Sp. Gr.
Chrompicotite	12.13	56.54	18.01	14.08	4.115
Magnochromite	29.92	40.78	15.30	14.00	4.02
Mitchellite (a)	29.28	39.95	13.19	17.31	—
Mitchellite (b)	7.82	57.80	18.18	11.62	—
Chromhercynite	27.12	38.64	27.00	5.33	4.415 (c)
Picotite	56.00	8.00	24.90	10.30	4.08

(a) from Corundum Hill, N. C.; (b) from Price Creek, N. C.; (c) contains 0.61% Fe_2O_3 , 1.10% MnO , 0.28% SiO_2 , and 1.25% H_2O .

The formulas are next calculated on the basis of magnesia replacing ferrous iron, and alumina replacing chromic oxide..

Chrompicotite	1:1.17	(42 Fe · 58Mg)O · (24 Al · 76Cr) ₂ O ₃
Magnochromite	1:1.01	(38 " 62 ") (52 " 48 ")
Mitchellite (a)	1:1.12	(30 " 70 ") (52 " 48 ")
Mitchellite (b)	1:1.24	(47 " 53 ") (17 " 83 ")
Chromhercynite	1:0.98	(74 " 26 ") (51 " 49 ")
Picotite	1:1.00	(58 " 42 ") (92 " 8 ")

(Note:—Formula computed on basis of 100 R''O · 100 R'''₂O₃).

Chrompicotite and magnochromite have approximately the same amount of bivalents, although the ratio of alumina to chromic oxide varies. This suggests that magnochromite is nearer the aluminates than the chromates. There is little difference between magnochromite and the Corundum Hill mitchellite (a). The varieties, magnochromite, mitchellite and chromhercynite are closely related to the aluminates. Chrompicotite and mitchellite (b)

carry the most chromic oxide but there does not appear to be enough difference chemically to warrant the name mitchellite. Approximately 30% of the collected analyses show as much or more chromic oxide as the type chrompicotite. This mineral species has 12.13% alumina, and 34% of the analyses studied carry more than 10% alumina. Of these, only 12% show more than 55% chromic oxide. Less than 30% of the so-called chromites analyzed are richer in chromic oxide than chrompicotite. These four predominating chromic-spinels have only four oxide variants and accordingly fall within type IIIa.

Magnochromite is listed with 40.78% chromic oxide and 29.9% alumina. Four of the collected analyses show more than 25% alumina and none of these contain more than 45% chromic oxide.

Chromhercynite is reported as showing 38.53% chromic oxide and 27.12% alumina. These percentages overlap those cited for magnochromite. Picotite, more strongly hercynitic than chromitic, carries only 8% chromic oxide and 56% alumina. None of the analyses studied carry as much alumina and only 2 have less than 10% chromic oxide.

If the limits of alumina are set at 15% and 25% only 37 chromite analyses fall within the range, and 8 of these analyses show between 45 and 55% chromic oxide. Alumina less than 10% is encountered in 68 analyses. Most of the chemical analyses of chromite are really representative of chrompicotite or closely related to it.

A STUDY OF CHEMICAL TYPES

Type IIa.

This is the closest approximation to the pure chromite molecule. Eight analyses of normal ratios are considered. The formula for the group is: $100\text{FeO} \cdot (23\text{Al} \cdot 77\text{Cr})_2\text{O}_3$. The range in ratios of the oxides are: alumina to chromic oxide—from 1:1.4 to 1:22; alumina to ferrous iron—from 1:2.4 to 1:20; chromic oxide to ferrous iron—from 1:0.9 to 1:1.7. The limits of the oxides and their relative abundance is shown in figures 1 and 1a. The acid radicle in IIa corresponds to chrompicotite, (See Fig. 5) with FeO slightly higher than normal. It is believed that ferric iron was not determined in these analyses.

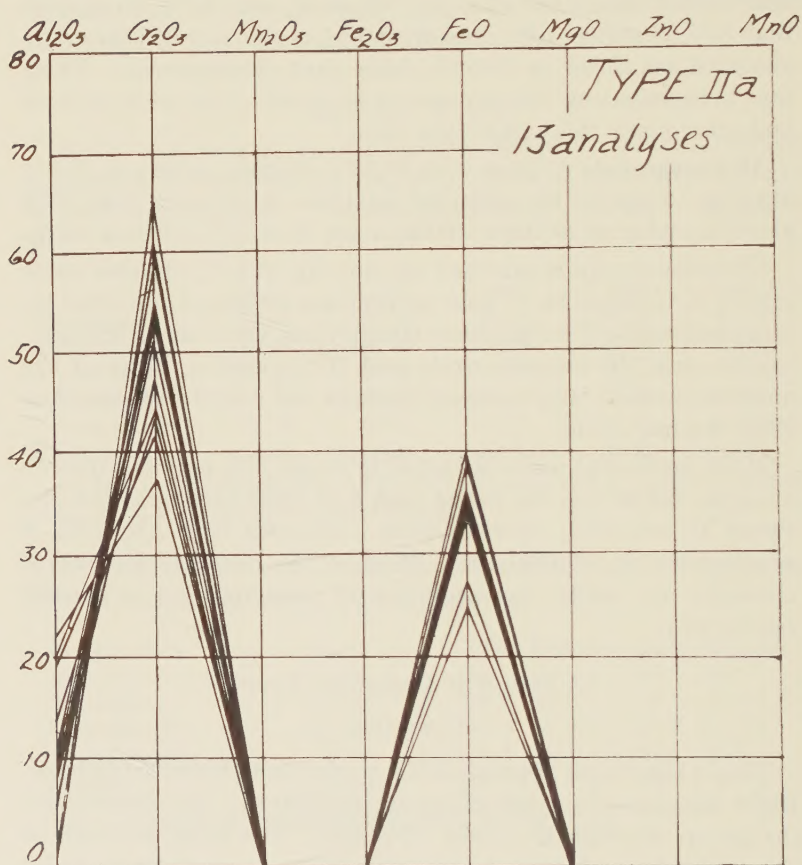


FIG. 1.

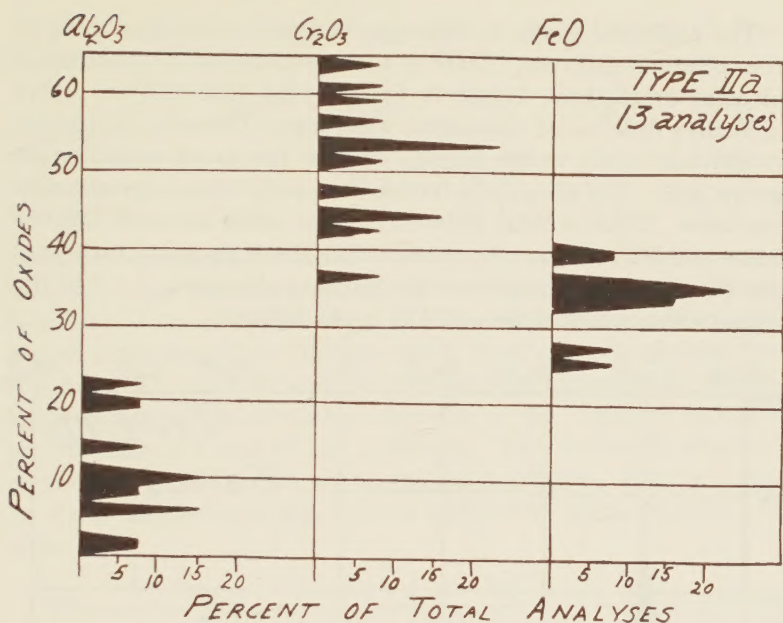


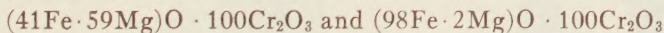
FIG. 1a.

Type IIb.

One analysis of this type is included and is expressed by the formula $100FeO \cdot 15 Fe_2O_3 \cdot 85 Cr_2O_3$. No deductions are made from this analysis.

Type III.

Two analyses fall in this type and because of the wide variation in their formula both are listed:

*Type IIIa*

The same as type III with alumina added. This is the largest group in the study and includes 64% of all the analyses. This type is compared with the varietal types cited earlier. Subnormal ratios occur in 15% of the analyses, 27% are normal and 58% are abnormal. The normal group will be discussed in full.

The average formula of the 25 normal analyses is: $(64Fe \cdot 36Mg)O \cdot (28Al \cdot 72Cr)_2O_3$. The acid radicle is nearer chrompicotite but the base is closely related to chromhercynite (See Fig. 5).

The abnormal group of this type includes more than 33% of the collected analyses. There is a range in ratios of trivalent to bivalent oxides from 1:1.10 to 1:1.94, with such analyses rather uniformly distributed throughout the range. The ratio of alumina to chromic oxide varies slightly despite the great range in the group ratio. The alumina to ferrous iron ratio remains practically the same. There is little difference in the ratios between chromic oxide and ferrous iron. It appears that the high group ratios are due to magnesia. The ratio of the latter to alumina is 2.3:1 in the lowest abnormal analysis and 4:1 in the highest.

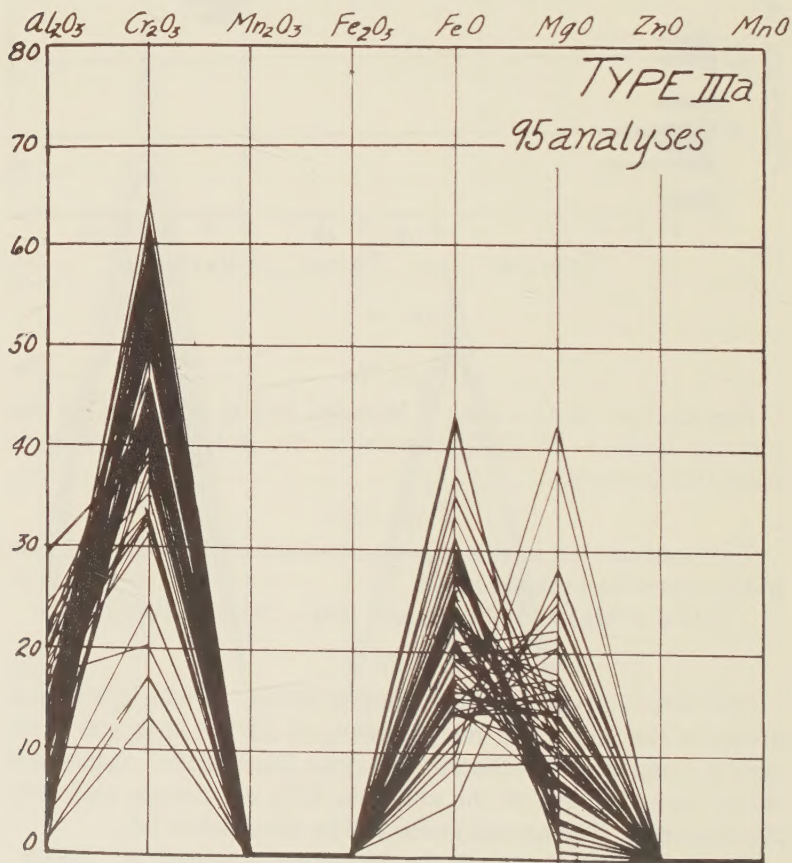


FIG. 2.

The average percentage composition of the divisions of this type, based on normality are:

	Al_2O_3	Cr_2O_3	FeO	MgO	Ratios
Subnormal group	15.7	57.8	19.4	7.1	1:0.77
<i>NORMAL GROUP</i>	13.7	54.9	23.3	7.1	1:1.02
Abnormal group	10.4	55.2	22.5	11.8	1:1.37
Average of type	11.9	54.4	21.8	11.6	1:1.8

Alumina decreases more rapidly than chromic oxide. This increase in ratio is apparently expressed by an increase in magnesia. When total trivalents are higher than total bivalents alumina is usually higher with respect to chromic oxide than when conditions are reversed. The ratio between ferrous iron and magnesia shows the latter increasing in amount as the sum of the bivalents becomes greater than the sum of the trivalents. This indicated effect of magnesia is suggestive of undetermined ferric iron. Figures 2 and 2a show the limits of the various oxides and their relative distribution.

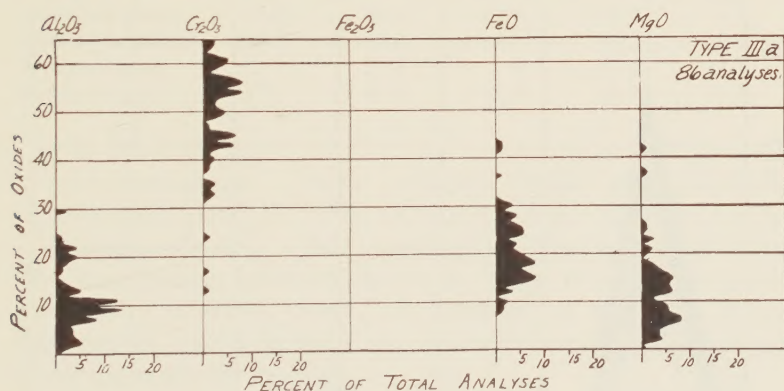


FIG. 2a.

Type IIIc.

This is the second largest group of analyses and includes 15 normal ratios. The average formula of these analyses is: $(37\text{Fe}'' \cdot 67\text{Mg})\text{O} \cdot (7\text{Fe}''' \cdot 33\text{Al} \cdot 60\text{Cr})_2\text{O}_3$. The outstanding feature here indicated is that magnesia is higher than ferrous iron. The type is more closely related to magnochromite than to any other. Alumina increases with respect to ferrous iron but decreases with respect to chromic and magnesia oxides. The ratio of ferric to

ferrous iron, compared with the subnormal group, has doubled.

If the abnormal group of this type is compared with the abnormal group of IIIa it is noted that the proportion of alumina to chromic oxide remains about the same. The introduction of ferric iron has not visibly affected this ratio. A comparison of figure 3 with figure 2 shows the peak of alumina has moved upward. The ratio of alumina to ferrous iron is not greatly changed but magnesia has gained fully 20% with respect to alumina of type IIIa. The ratios of chromic oxide to ferrous iron and magnesia remain much as they were in type IIIa. The entire 31 analyses of this type give an average formula of $(43\text{Fe} \cdot 57\text{Mg})\text{O} \cdot (8\text{Fe} \cdot 29\text{Al} \cdot 62\text{Cr})_2\text{O}_3$.

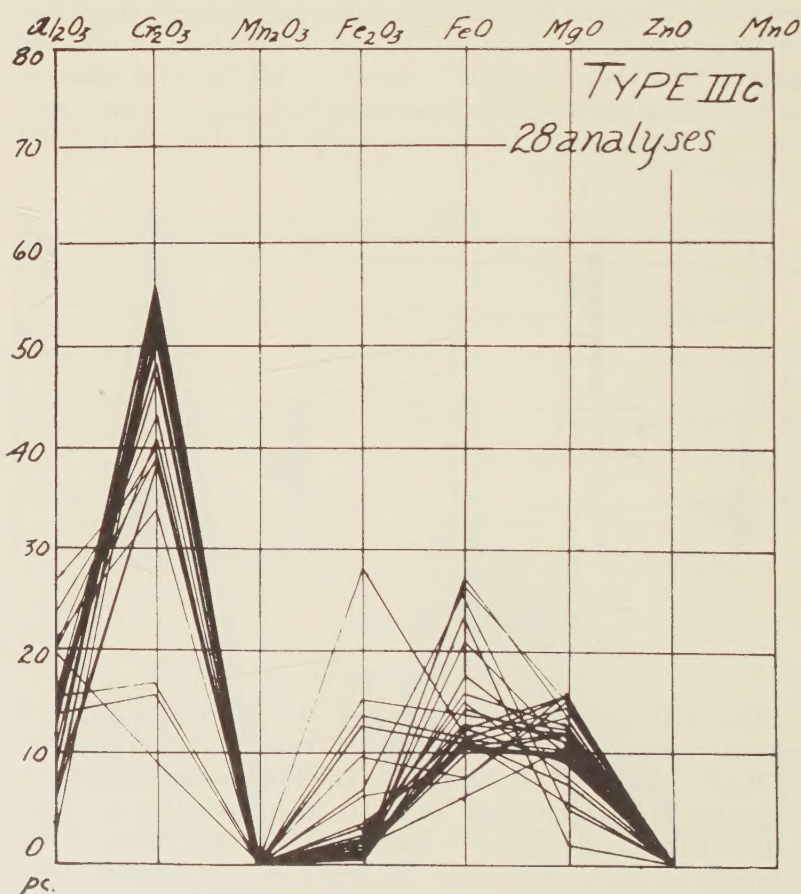


FIG. 3.

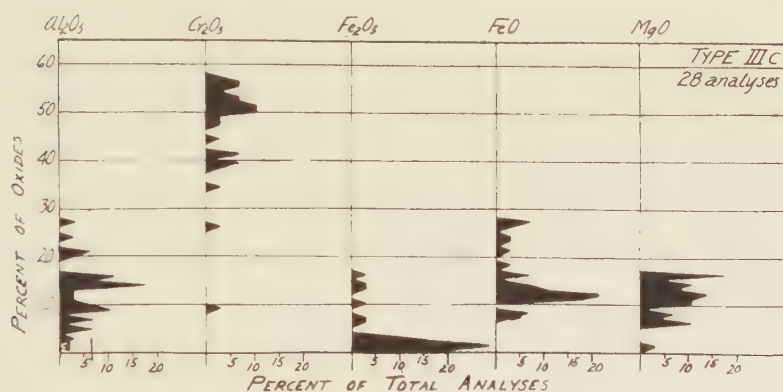


FIG. 3a.

SUMMATION OF TYPE IIIc.

1. By analyses

	Al ₂ O ₃	Cr ₂ O ₃	Fe ₂ O ₃	FeO	MgO
Subnormal group	14.0	49.2	12.4	15.2	9.2
NORMAL GROUP	17.7	47.1	6.0	14.4	14.8
Abnormal group	11.4	52.8	1.8	22.5	11.2
Average of type	17.2	49.0	66.3	15.8	11.7

2. By formula

Subnormal group (48Fe · 52Mg)O · (14Fe · 25Al · 51Cr)₂O₃

NORMAL GROUP (37Fe · 67Mg)O · (7Fe · 33Al · 60Cr)₂O₃

Abnormal Group (52Fe · 48Mg)O · (4Fe · 23Al · 73Cr)₂O₃

The outstanding relations shown in Type IIIc are: magnesia continually increases toward the extremes of abnormal ratios. The mineral called chromite moves toward magnesiochromite as abnormal ratios are reached.

Type III d

Four of the 151 analyses show this combination. No effort is made to correlate results. The analyses follow:

No.	Al ₂ O ₃	Cr ₂ O ₃	Fe ₂ O ₃	Mn ₂ O ₃	FeO	MgO
149	9.40	55.40	1.78	1.10	16.39	12.72
150	17.00	37.31	3.80	1.12	35.12	3.08
151	17.23	37.03	0.71	1.16	23.95	9.94
152	0.48	31.20	27.72	4.18	14.79	10.92
153	10.23	43.76	—	1.95	21.27	15.25

SUMMATION OF OXIDE RELATIONSHIPS

In figure 4 the frequency of percentages of oxides is plotted for all analyses considered. The bulk of the analyses show chromic oxide well above 40%, but alumina is massed around 10%. Ferrous iron extends over a considerable range although magnesia is somewhat restricted and is most abundant between 8 and 12%.

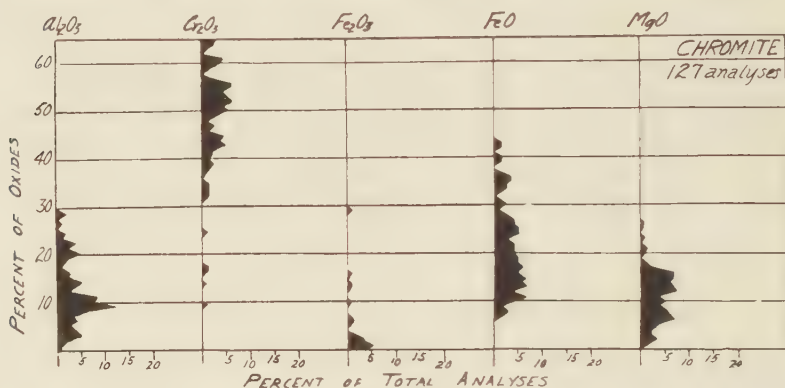


Fig. 4.

A comparison of figures 1a and 2a shows interesting facts. When magnesia replaces ferrous iron, in part, the majority of analyses show less alumina, the peak of the latter being in the neighborhood of 10%. Chromic oxide reaches its high point when magnesia is not present. (This is not shown in figure 2). It is natural that the peak of ferrous iron should drop as magnesia increases. Ferric iron is in all probability replacing chromic oxide and not alumina. This indicates that these analyses are more closely related to the ferrate spinellid than to the aluminate variety. It is inferred from a study of the graphs that magnesioferrite enters into those chromites that contain ferric iron in substantial amounts.

Figure 5 shows a graph representing varietal species superimposed on figures 1, 2, and 3, illustrating variations in oxides. A study of this figure gives the following results:

1. Alumina is highest in type IIIa, although all types show the same lower limits.
2. High values of chromic oxide occur in types IIa and IIIa. In the former there is no magnesia.
3. High and low values of ferric iron are not restricted to any particular type.

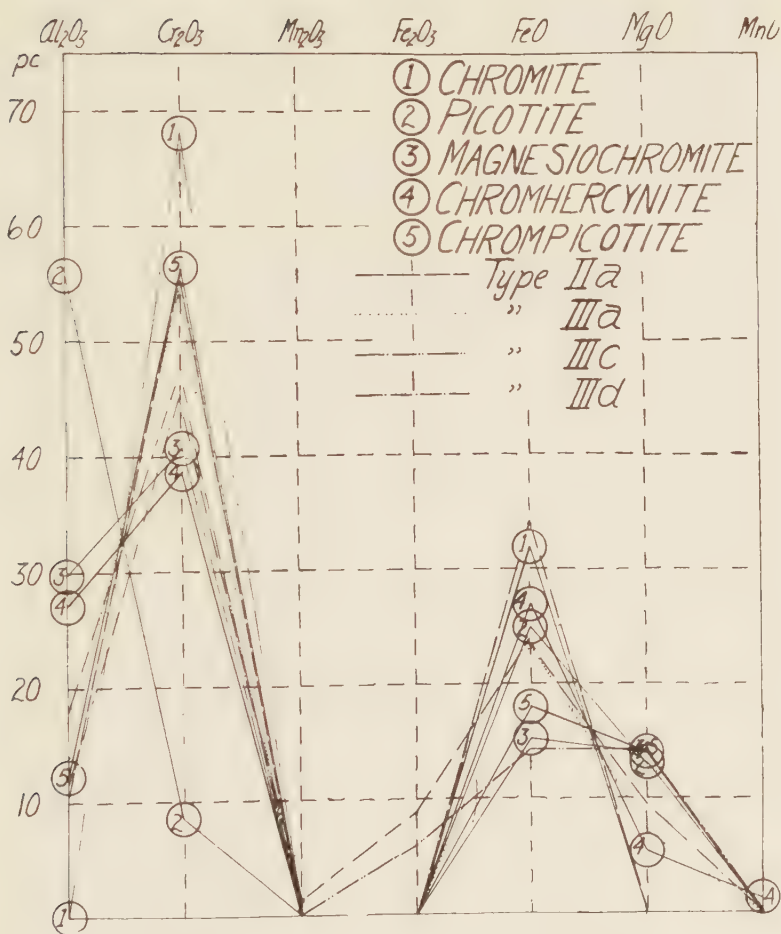


FIG. 5.

The analyses as a whole show that some correlative value may be attached to the replacement of iron by magnesia and chromic oxide by alumina and ferric iron. Application of such values to individual analyses fails. As a rule, however, when ferric iron is present, magnesia will dominate ferrous iron. When ferric iron replaces a trivalent element, chromic oxide is more affected. From these facts it follows that magnesioferrite must enter the composition of chromites.

In figure 5 where the averages of the four prevailing chemical types of chromite are plotted against the analysis of the original varietal type another comparison is afforded. Some of the deduced facts are:

1. No type average approaches the high chromic oxide of the theoretical chromite, although in type IIa ferrous iron is higher than in the pure chromite molecule. Ferric iron must have been present in those analyses.

2. There is considerable variation in average oxide content of the so-called chromites.

3. The majority of all chromite analyses recorded are closely related to the varietal types, magnesiochromite, chromhercynite and chrompicotite.

(a) Type IIIa corresponds closely to chrompicotite acid radicle and picotite-chromhercynite base.

(b) Type IIa is related to chrompicotite acid radicle and to a chromite base.

(c) Type IIIc bears a closer relation to the alumina of chrompicotite and chromic oxide of magnesiochromite when the acid radicle is considered, but to a magnesiochromite base.

Therefore, the majority of chromites are considered as intermediate members between chrompicotite and magnesiochromite.

MINERAL ANALYSIS OF CHROMITE

To ascertain the mineral analysis of chromite it is necessary to record some previously deduced values.

Normal ratios only are given. These are expressed in molar amounts.

	Al_2O_3	Cr_2O_3	Fe_2O_3	FeO	MgO
Type IIa	109	390	none	505	none
Type IIb	none	439	75	486	none
Type III	none	422	none	238	341
Type IIIa	135	359	none	324	178

Picotite	457	43	none	290	214
Magnochromite	260	237	none	190	312
Chromhercynite	257	244	none	365	129
Chrompicotite	108	340	none	227	320
Type IIIc	163	293	none	187	320

Two methods of computing mineral analyses from the above may be followed:

(1) Regard all FeO or Cr_2O_3 as entering the molecule chromite. Excess of either is then distributed in proportion among the remaining oxides.

(2) Distribute all bivalents on a proportionate basis to the trivalents.

Alumina is in excess in type IIa and in chromhercynite when the first method is used, likewise ferric iron is in excess in IIb, and magnesia in III, IIIa, IIIc, in picotite and chrompicotite. Ferrous iron is in excess only in picotite.

When the second method of calculation is used the following excesses are noted: chromic oxide in IIa and chromhercynite; ferric oxide in IIa; alumina in picotite and chromhercynite; magnesia in III, IIIa, magnesiochromite, chrompicotite and IIIc; and ferrous iron in the same types and varietal species as magnesia.

The study of either method shows that the mineral called chromite is not a simple mineral expressible by a definite formula. There is no relationship between the ratios of the bivalent or trivalent oxides in one specimen of chromite owing to the lack of uniformity of mixing of the spinellid molecules to form the mineral. The simplest formula that may be used to express the mineral composition is: 4 Chromite + 1 Hercynite, and the most complex variations are shown in IIc. Chromite is usually a combination of the pure chromite molecule plus the so-called magnesiochromite of Bock, hercynite and spinel. Magnesiochromite represents a spinellid that stands between spinel and chromite. The varietal types plotted with spinel and chromite show a transitional series—spinel-magnesiochromite-chromhercynite-chrompicotite-chromite. Chromite, as a mineral, represents varying proportions of these species and none of the latter may be represented by a definite chemical formula.

The study of the analyses indicates the probable presence of a pure magnesium chromite to which the name magnochromite

might be given to differentiate it from the chromite sub-species, magnesiochromite.

Spinel, hercynite, supposedly pure chromite and magnochromite are the end members of a four component diagram and within the limits of this diagram all non-ferric chromite will fall. When ferric iron is present, magnesioferrite must be added to the series.

CONCLUSIONS

I. *Chemically*

1. Chromite as a pure $\text{FeO} \cdot \text{Cr}_2\text{O}_3$ occurs only in meteorites.
2. There is a wide variation in the amounts of oxides that enter into both the acid and base of the mineral called chromite.
3. Practically all chromites analyzed show one or more oxides in excess. This excess may be caused by:
 - (a) Improper separation of chromite from gangue.
 - (b) Incomplete analysis.
 - (c) Solid solution of oxides within the chromiferous spinellid.

II. *Mineralogically*

4. Various members of the spinellid group are isomorphous with each other, but all the members cannot be arranged in a definite isomorphous series.
 - (a) According to Rettger's law one of the proofs of isomorphism between related species is that the physical properties of such mixtures are continuous functions of percentage composition.

The spinellids, taken as a group, do not show such a relationship when chromic oxide, alumina, ferric iron, ferrous iron, or total iron are plotted with index of refraction, specific gravity, etc.

- (b) Chromite does not contain zinc and cannot be a true variant of a series which contains gahnite.
- (c) The following isomorphous series are indicated within the spinellid group:

- I. Spinel-Magnochromite-Chromite.
- II. Magnetite-Kreitonite-Dysluite-Gahnite.
- III. Spinel-Magnesioferrite-Magnetite.
- IV. Gahnite-Spinel-Franklinite.

- (d) The atomic volumes of the oxides of the spinellids are:
- | | | | |
|-------------------|------|---------------------|------|
| alumina..... | 9.98 | zinc oxide..... | 9.50 |
| chromic oxide.... | 7.50 | manganous oxide.... | 7.10 |
| manganic oxide... | 7.40 | ferrous oxide..... | 6.80 |
| ferric oxide..... | 7.10 | magnesia..... | 6.70 |

On the basis of exchange of acid radicles the series would be aluminates-chromates-manganates-ferrates. Dividing such a series by the bases there would be:

- (1) aluminates: gahnite-manganspinel-hercynite-spinel.
- (2) chromates: chromite-magnochromite.
- (3) manganates: heterolite-hausmannite-ferromanganate.
- (4) ferrates: franklinite-jacobsite-magnetite-magnesioferrite.

Chromite is related to the mafic end of the aluminate series, and apparently is not related in any way to the manganates. It is related to the ferrates only by way of magnetite and magnesioferrite.

5. The spinellids, which have always been regarded as an isomorphous series, have variants that are predominantly manganiferous and zinciferous. The chemical analyses of the mineral called chromite do not harmonize chromite with these two types of spinellids.
6. Finally the mineral called chromite is not a definite mineral and cannot be regarded as a member of a definite isomorphous series, although the three, four, five or six spinellids which make up chromite are interrelated.

III. *Optically*

7. The chemical composition of the mineral called chromite is roughly indicated by the color of the mineral in thin section. Low chromic oxide content as in picotite, is characterized by a yellowish brown translucency, and high chromic oxide content by a deep cherry red to coffee brown color.
8. Anastomosing black, opaque lines traverse translucent chromite grains and indicate either: (1) the presence of a foreign substance which may be present as a solid solution in the mineral, or (2) iron oxide deposited as a cement along narrow or incipient fractures.

SOME NEW IMMERSION MELTS OF HIGH REFRACTION

TOM. BARTH.

(*Fellow of the International Education Board*)*

There have been difficulties in finding good media of high refraction for refractive index determinations with the microscope. Up to an index of about 2.1 good melts of iodine and piperine can be obtained. Above this value melts of selenium and sulphur have been used, and for still higher values melts of selenium and arsenic trisulfide.

However, these melts are not very convenient to use; they are highly colored and many are opaque for all but the red rays. If, therefore, the powder to be examined is itself colored, or nearly opaque, which often is the case for substances with high refraction, it is almost impossible to obtain satisfactory results. For this reason better melts of high refraction (above 2.3) are highly desirable.¹

The halogen compounds of thallium will render good service if used as high refraction immersion media. They are isotropic and very transparent; they are easily prepared and melted on an object glass (or better, between two cover glasses) over a low flame.

$TlCl$ can be precipitated from a solution of a thallos salt (e.g. Tl_2CO_3) by the addition of a soluble chloride (e.g. KCl). It melts at $426^\circ C$ between two cover glasses and recrystallizes on cooling to a limpid, thin, continuous sheet consisting of homogeneous, isotropic crystals. Its index of refraction for different wave lengths is given in Fig. 1.

$TlBr$ is prepared in the same way as $TlCl$. It melts at $450^\circ C$. It is colorless in thin sheets. Its index of refraction is shown in Fig. 1.

TlI is also prepared in the same manner as $TlCl$. It melts at $435^\circ C$ and will on cooling crystallize in a cubic modification, which, however, at about $170^\circ C$ inverts into an orthorhombic modification (see later).

* This investigation was carried on in Dept. of Mineralogy and Petrography, Harvard University.

¹ For literature references, see E. S. Larson, *Microscopic determination of minerals*, U. S. G. S. Bull. 679, 1921.

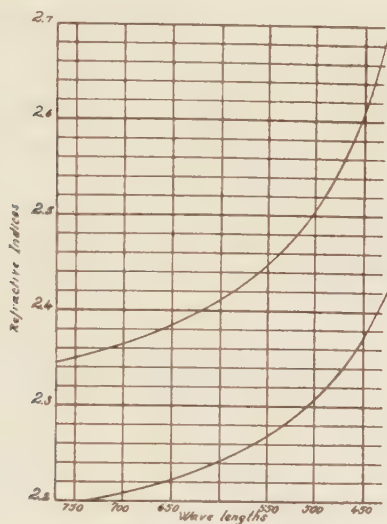


FIG. 1. The refractive indices of TlCl (lower curve), and TlBr (upper curve) for different wave lengths.

Mixed Crystals of TlBr and TlI. TlBr and TlI form homogeneous mixed crystals in all proportions and these crystals are isotropic and suitable for immersion media. Precautions should be taken in the preparation of these compounds. They are easily obtained by direct precipitation of the mixed crystals by adding a solution of a mixture of KBr and KI (in the desired proportions) to a cold solution of Tl_2CO_3 .

If this precipitation is made in hot solutions the precipitated mixed crystals will not correspond in composition to that of the added solutions, but owing to the relatively high solubility of TlBr in hot water, the crystals will be richer in iodine than the solution.

If on the other hand this precipitation is carried out in cold solutions, TlBr is so insoluble that practically all of the added bromine ions will be precipitated, and the resulting mixed crystals correspond exactly to the added solutions. The resulting mixtures are good immersion media whose indices of refraction cover the range between 2.4 and 2.8 (Na light), and they have a greater transparency than any other of the proposed immersion media of equal refractive power (Fig. 2).

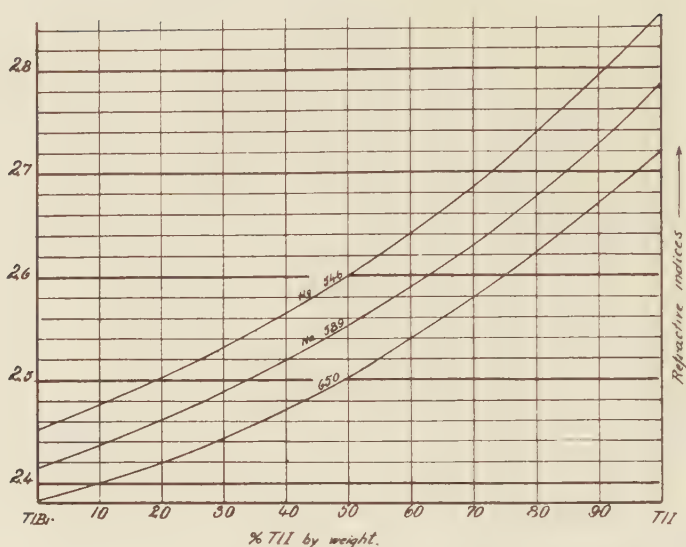


FIG. 2. The refractive indices of the mixed crystals of TlBr-TlI for three different wave lengths.

The bromine-rich crystals are transparent for almost all kinds of light, whereas the iodine-rich mixtures are opaque for the violet and blue rays. This does not mean, however, that the iodine-rich crystals are inconvenient to use, or that they are only semi-transparent for the longer wave lengths. The fact is, these compounds have a very sharp absorption border, and thus even in the iodine-rich crystals, though they are quite opaque for the indigo-blue rays, are almost as transparent as glass for the yellow sodium light. Even the green mercury light passes through them very easily. Fig. 3 shows graphically the values of the wave lengths

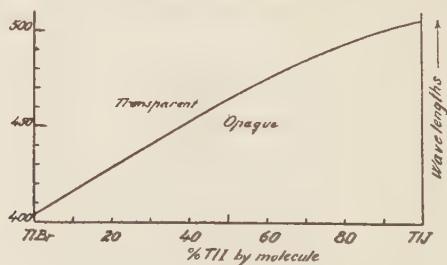


FIG. 3. The approximate position of the absorption border of the mixed crystals of TlBr-TlI.

for which the different mixed crystals very suddenly become opaque.

It should be added that the pure iodide and the iodide-rich mixed crystals are not stable in the cubic modification at ordinary temperatures. They invert into a birefringent (orthorhombic) modification,² but even in the mixed crystals with 80% TII this inversion goes on so slowly that the crystals often remain cubic for days, and no precautions need be taken. The pure TII, however, will invert more rapidly, and at a somewhat elevated temperature it changes completely in a few seconds. If, however, the melt is chilled (by pressing against a wet handkerchief) the crystals will remain cubic long enough for the necessary investigations with the microscope.

² This should not be confused with an anomalous birefringence which now and then appears in the quickly cooled melts. As this birefringence is very weak, it does not involve any further difficulties in the determination of the refraction.

THE EXHIBIT ILLUSTRATING FLUORESCENCE AT THE ACADEMY OF NATURAL SCIENCES OF PHILADELPHIA¹

SAMUEL G. GORDON, *Philadelphia, Pennsylvania.*

In preparing this exhibit at the Academy of Natural Sciences of Philadelphia, two sources of ultraviolet radiation were considered and tested: the quartz mercury-vapor lamp (of the Hanovia and Cooper-Hewitt types), and carbon arcs with cores of iron.

The quartz mercury-vapor lamps have the great disadvantage in that they must be tilted before they will ignite, and very often do not light with a single tilting. The museum authorities would thus be compelled to install mechanical devices which would tip the lamp, or else permit the tilting to be done by an attendant or the visitor.

While the maximum fluorescent effects are often attained only after an exposure of many minutes, it is also interesting to note the gradual development of these auroral effects. Certain installations permit of continual exposure to the mercury-vapor lamp and in addition use an electric light to obscure the fluorescence when it is desired to observe the minerals under ordinary illumination.

SOURCE OF ULTRAVIOLET RADIATION. It was finally decided that an automatic carbon arc lamp would give the best results in a museum exhibit, and the new Eveready Sunshine Lamp² burning four carbons was selected. The carbons used are of the National "C" Therapeutic type which are polymetallic in composition, containing a core of iron, nickel and aluminum, with some silicon, and yielding a maximum amount of ultraviolet radiation.

As the character of the fluorescence depends upon the wave lengths of ultraviolet radiation, obviously different sources of ultraviolet light will cause marked differences in the observed results. The fluorescence of calcites, for example, is apt to be disappointing, when a carbon arc-lamp as described above is used. However, for museum purposes, striking effects can be obtained on most fluorescent minerals, while the automatic feature of a carbon arc makes for a dependable, and practical exhibit.

The weights used to pull the carbons down require adjustment about once an hour if the apparatus is in continuous operation.

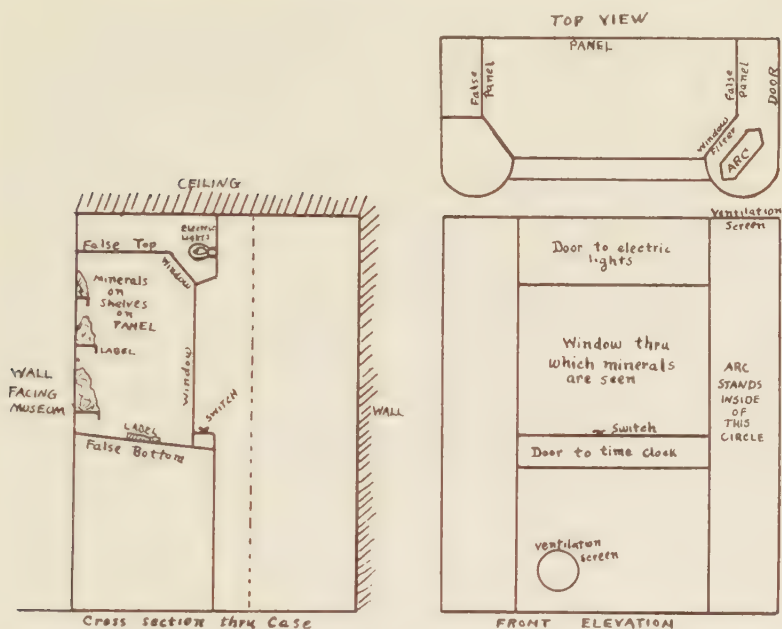


FIG. 1

COLOR FILTER. The light from the arc lamp is filtered through a Corning³ heat resisting red-purple ultra (unpolished) filter. As this glass could not be obtained in sizes larger than 6 1/2 inches square, four 5 inch squares were cemented together to form a window in the case.

ELECTRIC LIGHTS. In addition to the ultraviolet lamp, three 50 watt electric light bulbs of the "daylight" type are used to illuminate the minerals when the ultraviolet lamp is not in operation.

THE SWITCH. The switch consists of a No. 706 single action, single pole Kwixset⁴ automatic timing clock, connected with a Dunco⁵ double-pole magnetic relay. The carbon arc-lamp and the electric lights are connected directly to the magnetic relay which is operated by the Kwixset time clock.

The action of the switch is as follows: Just the key of the switch projects above the sill in front of the case, and the hole in the sill is just large enough to permit the key to be turned to the one minute point. A visitor coming to the case finds it illuminated by means of the electric light. A label behind the key states: "To

operate, turn this switch." Upon doing so, the electric light goes off, and the arc light is turned on, in a single operation. The arc light remains on for one minute, at the end of which it is extinguished automatically, and the electric lights again flash on.

THE CASE. The case (Fig. 1) was built of 2 by 4 inch beams covered with celotex. It contains the carbon arc-lamp in a circular pillar in the right hand front corner of the case; three electric lights hidden in the top; and a panel to hold the minerals which are viewed through a plate glass window.

The panel, 36 by 50 inches, is a single 5 ply wood board, with 18 shelves, each just large enough to hold its particular specimen. The shelves were fastened to the board by means of small angle irons. The panel is fastened to the beams of the back of the case and the case is equipped with a false ceiling, bottom, and false panels on the sides. The entire interior of the case, including the shelves, is covered with black velvet.

The electric lights are placed in the false top, and illuminate the minerals through a concealed window.

The carbon arc is placed in a circular pillar, just large enough to hold the entire apparatus and permit rotation of the top to adjust and replace the carbons. The arc is reached through a door in the side of the case, and the entire apparatus can be lifted through this door. Just in front of the arc is a window, 10 inches square, made of the Corning heat resisting ultra U. V. red purple (unpolished) that serves as a glass filter.

A ventilation screen was placed in the front of the case near the floor, and the space above the electric lights and the carbon arc is open to the ceiling of the hall.

The minerals are viewed through a plate glass window 30 by 36 inches.

Projecting up from the sill in front of the window is the key of the switch. The timing clock, and magnetic relay are concealed in a box below the sill.

PLACING OF THE CASE. The case was built in a corner of the mineral hall, in such a manner that the back of the case faces the hall (Fig. 2). The part facing the mineral hall was left in the natural celotex finish. The walls shown in the figure, ceiling, and front of the case (about the window) were painted a dull black. The two circular pillars at the sides of the case, one of which forms

a place for the arc light, serve to shut out the light from the direct view of the visitor. This is an important point, as the intensity of the fluorescence is greatly diminished by the introduction of any extraneous light.

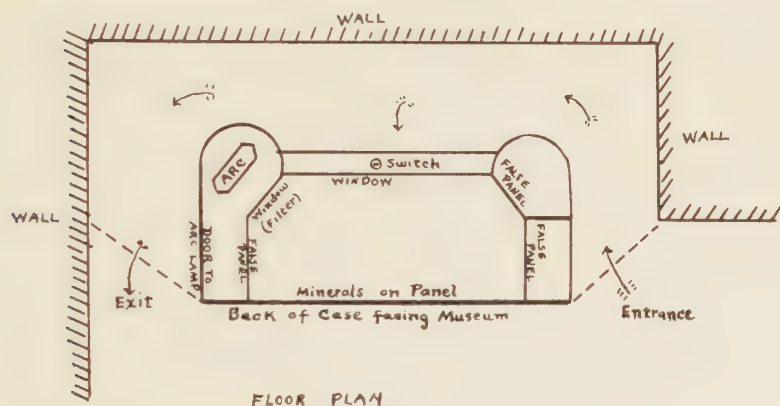


FIG. 2

The position of the ceiling of the case is indicated by the dashed lines in figure 2. No doors or curtains were added, the case alone being used to exclude the light.

THE LABELS. Fastened to the velvet-covered shelf under each mineral is a label, a typical one of which reads:

AUTUNITE
 $\text{CaO} \cdot 2\text{UO}_3 \cdot \text{P}_2\text{O}_5 \cdot 8\text{H}_2\text{O}$
 LIMOGES, FRANCE
 Gift of T. B. Wilson

The labels are of heavy white card board painted over with carbon black. The information is painted on with a fluorescent paint⁶ which is a greenish yellow by electric light, and fluoresces with an intense orange glow under the ultraviolet rays.

The general explanatory label is a cleavage slab of microcline, containing the information given below, in two parts: one portion entitled "Reflection," and the other "Fluorescence." The wording of the part called "Reflection" is painted on the microcline in letters of a crimson red water color. Between the lines of the red letters, the data on "Fluorescence" have been painted with a paint which is practically invisible in electric light, but which fluoresces with a greenish glow. The part called "Reflection" is,

therefore, visible only under the electric light, and the lines entitled "Fluorescence" appear only under the ultraviolet rays.

A more complete explanatory label appears at the entrance to the exhibit.

REFLECTION

These minerals are now seen under an electric light which emits light of all colors. The colors shown by the minerals are, therefore, those of the color of light they reflect, as the other colors are absorbed.

Now turn off the electric light

FLUORESCENCE

Ultraviolet rays are now falling on these specimens. These few minerals have the property of absorbing these rays and stepping them up to the wavelengths of visible light. The new light, created within the minerals from the invisible ultraviolet rays, is emitted as a cold glow.

THE MINERALS. Eighteen mineral specimens were selected for the exhibit because of the intensity of their fluorescence and the variety of color shown. These were selected after examining about 15,000 specimens, at night time. It was possible to do this as the arc light is portable, and could be rolled from case to case.

The minerals are listed in the table below, which gives also their fluorescent color. Most of these minerals are well known for their fluorescence, and only the wernerite and sodalite need further comment.

FLUORESCENCE OF WERNERITE FROM CANADA. The wernerite was labeled as coming from Grenville, Canada. It was found to be the *most fluorescent* of all of the minerals examined, exhibiting an intense lemon yellow color.

The mineral in daylight is barium yellow (Ridgway) in color. It was found to be optically negative, with the indices $\epsilon = 1.555$, and $\omega = 1.590$. It thus corresponds to:

Ma (Marialite)	$2\text{NaCl} \cdot 3\text{Na}_2\text{O} \cdot 3\text{Al}_2\text{O}_3 \cdot 18\text{SiO}_2$	70%
Me (Meionite)	$4\text{CaO} \cdot 3\text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$	30%

Associated with it is a colorless diopside, which appears black under the ultraviolet rays.

FLUORESCENCE OF SODALITE FROM GREENLAND.⁷ The sodalite is in large cleavage masses collected by the writer in 1923 at Tugtup Agtakorfia, Tunugdliarfik, Greenland, in the cliff formed by the largest of the naujaite masses in the lujavrite. It is practically colorless, excepting where it includes needles of aegirite. It fluoresces with a cadmium (orange) yellow color. Some inclusions of albite show a purple tint.

TABLE 1. THE MINERALS EXHIBITED

MINERAL	LOCALITY	COLOR	FLUORESCENT COLOR
Fluorite	Weardale, England	Violet	Bluish violet
"	" "	"	" "
"	Alston, England	"	" "
Hyalite	Bedford, New York	Colorless	Green
Autunite	Philadelphia	Yellow	Green
"	Limoges, France	"	"
Willemite	Franklin, N. J.	Pale green	Neva green
"	" "	" "	" "
Willemite and Calcite	Franklin, N. J.	Pale green White	Neva green Scarlet
Anglesite	Phoenixville	Colorless	Pale greenish
Brucite	Lancaster Co., Pa.	White	Pale bluish white
Wernerite	Grenville, Canada	Barium-yellow	Lemon yellow
Sodalite	Greenland	Colorless	Cadmium yellow
Aragonite	Girgenti, Sicily	White	Rose pink
Ruby corundum	Buck Creek, N. C.	Red	Scarlet

In addition, two fossils in the lithographic limestone from Solenhofen,—a crustacean and a fish,—are exhibited.

The minerals have been arranged on the panel so as to present a more or less harmonious distribution of the colors and intensities.*

FOOTNOTES AND REFERENCES

¹ An account of the exhibit illustrating fluorescence in the British Museum (Natural History) by Dr. L. J. Spencer appeared in this magazine, **14**, 33-37, 1929; in the *Natural History Magazine*, **1**, 291-298, 1928; with a reference in *Science* of December 7, 1928, p. 560 (taken from the *London Times*).

References to exhibits illustrating fluorescence in the Museums of the Peaceful Arts in New York City, and in the Buffalo Society of Natural Sciences appeared in *Science*, **69**, page 167, 1929.

² National Carbon Co., Inc., Cleveland, Ohio. This is a therapeutic lamp now on the market for \$137.50. The C carbons cost about 25c apiece. About one carbon a day is consumed.

³ Corning Glass Works, Corning, N. Y. The filters are described in Dr. Gage's booklet "Glass Color Filters" distributed free by the company. A particularly useful glass manufactured by this company is a faintly tinted didymium glass which cuts out the two sodium lines of the spectrum, and is superior to cobalt glass for examining flame colors.

⁴ H. C. Thompson Clock Co., 2032 Grand Central Terminal, New York City; \$15.00.

⁵ Struthers Dunn, Inc., 1130 Race Street, Philadelphia; Type 829 with 4 blow-out coils for direct current (\$17.00).

⁶ Purchased from Frank Hartman (Radium Products Co.), 1920 Walnut Street, Philadelphia, Pa.

⁷ Fluorescence in sodalite was described by T. Liebisch; *Sitzungsber. Preuss. Akad. Wiss., Berlin*, 1912, 229-240.

DAHLLITE FROM ST. PAUL'S ROCKS (ATLANTIC)

HENRY S. WASHINGTON, *Geophysical Laboratory.*

INTRODUCTION

The small islet group of St. Paul's Rocks or St. Paul lies in the middle of the Atlantic Ocean, in Lat. $0^{\circ} 55' 28''$ N. and Long. $29^{\circ} 22' 32''$ W. It is on the great "Mid-Atlantic Ridge," about half-way between the coast of Liberia and that of northeastern Brazil.

The group has a total length of about three-tenths of a mile north and south, and a breadth of about one-seventh of a mile east and west. It consists of four rocky islets, the highest point being about 64 feet above the level of the sea.

The islets have been visited for scientific purposes several times. The first landing was by C. Darwin from the *Beagle* in 1832,¹ and the second during the *Challenger* expedition in 1873.² Later landings were those from the *Quest* of the Shackleton-Rowett Expedition in 1921, and from the *Meteor* of the Deutsche Atlantische Expedition in 1925.³

During the visit of the *Quest* rock specimens were collected by Dr. G. Vibert Douglas, which were entrusted to me for petrographic study. The main results of this will appear in the forthcoming Report of the Expedition, which will be published by the Trustees of the British Museum, to whom I am indebted for their permission to publish in advance of them my study of the St. Paul phosphate rocks. I would also express my thanks to Dr. L. J. Spencer for his kindly aid in the matter.

All the islets consist of a black, very dense and compact dunite, which was studied many years ago by Father A. Renard of Belgium.⁴ According to my studies this dunite is composed of about 74 per cent of very fresh olivine, about 24 per cent of pyroxene (chiefly the jadeite, enstatite, and diopside molecules), and about 2 per cent of deep brown picotite. This peridotite shows evidence of metamorphism by pressure, in this respect and in its general character making St. Paul unique among deep-water

¹ Darwin, *Geol. Observ. Volcan. Islands*, 3d ed., p. 37, 1891.

² John Murray et al., *Voyage of H. M. S. Challenger*, Narrative, I, (1), p. 201, 1885.

³ O. Pratje, *Die deutsche Atlantische Expedition "Meteor," Vorbericht*, p. 59, 1925.

⁴ A. Renard, *Neues Jahrb.*, 1879, p. 390; *Voyage of H. M. S. Challenger*, Narrative, Appendix B, 1882, ditto, I, (1), p. 206, 1885.

oceanic islands. Renard arrived at results essentially the same as mine.

DAHLLITE. Darwin⁵ states that "the rocks of St. Paul appear from a distance of a brilliant white colour." This was also noted by the *Challenger* expedition, which recommends the erection of a lighthouse because of the consequent danger to navigation. The white appearance is caused by a deposit of guano formed from the droppings of the numerous sea-birds.

This substance, which is essentially tricalcium phosphate, occurs in two forms. One variety is a grayish white, glossy incrustation, with a pearly luster and thinly laminated structure. According to Darwin its hardness is approximately 5. He believed it to be "an impure phosphate of lime," as it does not effervesce with acids. None of this variety was present on any of the specimens at my disposal, and those examined by Renard showed only small quantities of it.⁶ The physical characters observed by him correspond to the description by Darwin. An analysis by Renard (made on 0.0175 gram) yielded: CaO 50.51, P₂O₅ 33.61, with traces of FeO, MgO, and SO₃. He concludes that it is essentially tri-calcium phosphate, with some calcium sulphate.

The second variety of phosphate rock is dull, rusty, and earthy-looking, with a very rough feel, and easily scratched by a knife. The colors are mostly in dull, light yellows, and some of the specimens are banded with darker streaks.

This variety is mentioned by Darwin, who speaks of a calcareo-ferruginous soft stone that forms veins. Douglas, in his notes, states that this rock forms dikes, but the chemical and microscopical study proves that this is not the case. Pratje speaks of great cracks (in the dunite) filled with a "sehr widerstandsfähigen sedimentären Material, das als Rippen herausgewitterte." He attributes their formation to the accumulation of material washed down by the spray and rains from the guano deposits above.

The appearance of this substance is most unpromising, but thin sections of several specimens were made and one from the Northeast Islet was specially studied. According to Douglas this forms a dike—really the filling of a crevice—in the dunite. This

⁵ Darwin, *Voyage of H. M. S. Beagle*, Chap. 1; *Geol. Observ. Volcan. Islands*, 3d ed., p. 38, 1891.

⁶ Renard, *Neues Jahrb.*, 1879, p. 390; *Challenger Voyage*, Narrative, 2, Appendix B, p. 21, 1882.

specimen is dense and aphanitic, most of it being a pale, dull yellow, with thin, almost black bands.

Thin sections show that the pale yellow portions are composed of a transparent, almost isotropic substance, most of which is colorless, but with yellowish patches. The texture of this is largely spherulitic. Scattered through this, and making up most of the dark bands, are many small, irregular areas of opaque black and slightly translucent dark brown, which look more like stains than grains. Here and there are small, very irregular patches of a colorless mineral that is birefringent and of slightly higher refractive index than the main substance. No cleavage is to be seen, but some small irregular areas are apparently twinned.

The optical properties of the main colorless (megascopically yellowish) substance were studied by Dr. Merwin and its X-ray structure was examined by Dr. Posnjak of the Geophysical Laboratory, to both of whom I am deeply indebted for their kind assistance.

The spherules are radiately fibrous, the fibers having parallel extinction, with ϵ in the direction of the elongation. Merwin reports that the mineral is uniaxial, with $\omega = 1.603$ and $\epsilon = 1.598$, "for the bulk of the material, but some of the spherules have an outer layer of somewhat higher refractive index." Posnjak states

TABLE 1. ANALYSES OF DAHLITE

	1	2	3	4	5	6
P ₂ O ₅	35.75	38.44	38.40	39.04	0.273	1.00
CaO	56.47	53.00	53.65	51.15	1.084	4.00
MgO	0.30	n.d.	n.d.	n.d.	.008	
(Al, Fe) ₂ O ₃	n.d.	.....	0.57	3.04		
FeO	n.d.	0.79	n.d.	n.d.		
(Na, K) ₂ O	n.d.	0.11	n.d.	n.d.		
SiO ₂	0.01	.....	.....	.....
H ₂ O+	3.91	1.37	2.10	(?)	0.217	1.07
H ₂ O	0.53					
CO ₂	3.36	6.29	5.30	3.90	0.076	
SO ₃	0.36	.....	.....	.....	0.005	
	100.69	100.89	100.02	97.13		

1. Dahllite. St. Paul's Rocks (Atlantic). Washington analyst.

2. Dahllite. Bamle, Norway. Bäckstrom analyst. Brögger and Bäckstrom, *Ofv. Ak. Stockholm*, **45**, p. 493, 1888. Ref. in *Zeits. Kryst.*, **17**, p. 426, 1890.

3. Dahllite, Mauillac, Quercy, France. Pisani analyst. A. Lacroix, *C. R. Acad. Sci.*, **150**, p. 1390, 1910.

4. Dahllite (podolite), Utschina River, Podolia, Russia. Tscherwinsky analyst. *Neues Jahrb. Centralbl.*, 1907, p. 279.

5. Molecular ratios of 1.

6. Oxide ratios of 1.

that the diffraction pattern appears to be completely identical with that of the fluor-apatite examined for comparison.

The material is completely soluble in dilute hydrochloric acid, with slight effervescence. An analysis made by me of the carefully selected yellow portion, which was part of that examined by Merwin and Posnjak, gave the results shown in No. 1 of Table 1. Some analyses of dahllite from other localities are given for comparison.

My analysis shows the presence of about 0.9 per cent of gypsum, while the formula for the dahllite portion may be calculated as $40\text{CaO} \cdot 10\text{P}_2\text{O}_5 \cdot 8\text{H}_2\text{O} \cdot 3\text{CO}_2$. This may be compared with that of Schaller for dahllite,⁷ $10\text{CaO} \cdot 3\text{P}_2\text{O}_5 \cdot \text{CO}_2 \cdot \text{H}_2\text{O}$, which he regards as the "correct" formula for dahllite. If we consider the unsatisfactory character of the material and its mode of origin,⁸ the formula given above may be written as: $30\text{Ca}_3(\text{P}_2\text{O}_5) \cdot 8\text{Ca}(\text{OH})_2 \cdot 2\text{CaCO}_3$. This reduces to the simplest general formula $3\text{Ca}_3(\text{P}_2\text{O}_5) \cdot \text{Ca}((\text{CO}_2, (\text{OH})_2)$. It is clear from the analyses here given (and from many others) that the composition of dahllite is somewhat variable, especially as regards CO_2 and H_2O , so that the formula $3\text{Ca}_3(\text{P}_2\text{O}_5) \cdot \text{Ca}((\text{CO}_2, (\text{OH})_2)$ may be regarded as the general one for this mineral.⁹

The pale yellowish mineral is, thus, obviously a dahllite, but one with more hydroxyl than carbon dioxide replacing the fluorine and chlorine of apatite. This chemical identification is confirmed by the observations of Merwin and Posnjak, although the refractive indices found by the former are somewhat lower than those found by Larsen¹⁰ for dahllite from an unnamed locality, ($\omega = 1.620$, $\epsilon = 1.609$). The mineral is certainly not identical with martinite, $5\text{CaO} \cdot 2\text{P}_2\text{O}_5 \cdot 1\frac{1}{2} \text{H}_2\text{O}$, from Curaçao¹¹ and from Ascension Island.¹²

⁷ W. T. Schaller, *U. S. Geol. Survey, Bull.* 509, p. 98, 1912.

⁸ CO_2 was determined by me as the difference between the loss on ignition and the total H_2O .

⁹ The formula given by Doelter (*Handb. Mineralchemie*, III, (I), p. 578, 1918), namely, $4(\text{Ca}, \text{Fe}, \text{Na}_2, \text{K}_2) \text{P}_2\text{O}_8 \cdot 2\text{CaCO}_3 \cdot \text{H}_2\text{O}$, is evidently erroneous.

¹⁰ E. S. Larsen, *U. S. Geol. Survey, Bull.* 679, p. 196, 1921.

¹¹ Cf. Dana, *System*, 6th ed., p. 830; E. S. Larsen, *U. S. Geol. Survey, Bull.* 679, p. 105, 1921.

¹² G. Richards, *Am. Mineral.*, 13, p. 399, 1928.

AN OCCURRENCE OF DUMORTIERITE NEAR QUARTZSITE, ARIZONA¹

ELDRED D. WILSON, *University of Arizona.*

INTRODUCTION

Since 1889, the occurrence of dumortierite in southwestern Arizona has been known, but only as detrital boulders in the Colorado River terrace gravels between Ehrenberg and Yuma. Such was the material from near Clip, Arizona, that was studied by Diller and Whitfield,² Ford,³ Schaller,⁴ and Bowen and Wyckoff.⁵ Clip is said by local old residents to have been situated across the river from Picacho, California.

In 1927, claims were located on certain dumortierized schist outcrops near Quartzsite, about 45 miles north-northeast of the Clip locality. These outcrops represent the first known Arizona occurrence of the mineral in place. The deposit is of further interest because the three isomeric aluminum silicates, andalusite, cyanite, and sillimanite, are associated with the dumortierite, and show alteration to pyrophyllite instead of to muscovite.

SITUATION

This dumortierite deposit is in west-central Yuma County, Arizona, about three miles southwest of Quartzsite and fifteen miles east of the Colorado River, in the northwestern portion of T. 3 N., R. 19 W., Gila and Salt River Base and Meridian. The deposit outcrops on the north side of a narrow re-entrant in the low, southeastern portion of an isolated group of hills that stand prominently above the plain near the eastern margin of the Dome Rock Mountains.

GENERAL GEOLOGY

These hills, which occupy an area about three miles long by two miles wide, are made up of steeply dipping schists of probable pre-Cambrian age, and are surrounded by desert detrital gravels. Microscopic study of the schists indicates them to be dominately

¹ Published by permission of the Director of the Arizona Bureau of Mines.

² *Am. Jour. Sci.*, 3d ser., vol. **37**, pp. 216-219, 1889; also *U. S. Geol. Survey, Bull.* **64**, pp. 31-33, 1890.

³ *Am. Jour. Sci.*, 4th ser., vol. **14**, pp. 426-430, 1902.

⁴ *Idem*, 4th ser., vol. **19**, pp. 211-224, 1905; also *U. S. Geol. Survey, Bull.* **262**, pp. 91-120, 1905.

⁵ *Jour. Wash. Acad. Sci.*, vol. **16**, pp. 178-179, 1926.

of igneous origin. Certain prominent members definitely represent rhyolites, and a considerable portion of the series is chlorite schist that probably was derived from igneous rocks. A minor portion of the series, on the other hand, is quartz-sericite schist that offers no field or microscopic evidence as to its origin.

In the vicinity of the dumortierite deposit, the schists strike about east-west and dip steeply northward. Minor faulting, principally along the strike of the schistosity, is evident.

THE MINERAL DEPOSIT

FORM AND STRUCTURE. The outcrop of the dumortierized phase of the schist trends approximately east-west and is divided into two segments, some 450 feet apart, by a tongue of the outwash gravels that also conceal its east and west limits.

The western segment outcrops with a length of approximately 200 feet and a maximum width of 35 feet. In it, the planes of schistosity strike nearly east-west and, as exposed in shallow cuts, dip 65° – 80° N.

The eastern segment outcrops with a length of approximately 300 feet and a maximum width of fifty feet. Throughout its western third, the planes of schistosity strike nearly east-west, but, for the eastern two-thirds, they strike about $S.70^{\circ}$ E. In this segment also, they dip steeply north.

CHARACTER OF DUMORTIERIZED SCHIST. A generalized section, from north to south across the western segment of the deposit, is as follows:

	THICKNESS IN FEET
(a) Gray, laminated pyrophyllite schist with a few microscopically visible dumortierite prisms. . . . .	.5 \pm
(b) Like (a), but thinly laminated.	1–2
(c) Largely cyanite, andalusite, sillimanite, and pyrophyllite. Contains a little dumortierite.	2/3
(d) Quartz vein with comb structure and containing crystals of rutile and cyanite.	1/3
(e) Like (c), but containing more dumortierite and grading into quartz mica schist.	30
(f) Outwash gravels	

MINERALOGY

Associated with the dumortierite are quartz, cyanite, andalusite, sillimanite, pyrophyllite, muscovite, hematite, magnetite, rutile, leucosene, pyrite, limonite, sapphirine (?), and some undetermined species.

Dumortierite ($8\text{Al}_2\text{O}_3 \cdot \text{B}_2\text{O}_3 \cdot 6\text{SiH}_2\text{O}_2 \cdot 2\text{O}$, Schaller): The dumortierite occurs as fibers and small prisms, both disseminated and in veinlets. Its fibers may be in divergent, parallel, or curved masses that in places are brush or comb-shaped in section. Groups of the parallel fibers show deep blue pleochroism in their long direction. The prisms generally are straight, but in places are forked or sharply bent. They show strong pleochroism, with X = deep blue, rarely violet; Y = colorless to yellow, rarely pale blue to violet; and Z = colorless to pale blue. This pleochroism for a given direction may vary within a single crystal. The mineral has biaxial character, negative elongation, and extinction X \parallel c.

Where disseminated, the mineral penetrates quartz, cyanite, muscovite, and pyrophyllite, but less commonly the andalusite and sillimanite. Within minerals other than quartz, the dissemination usually is rather sparse, so that the dumortierite is scarcely noticeable to unaided eyes. Within quartz, however, the dumortierite may be sufficiently abundant to color the rock a deep, dull, violet-blue that is near 53'' VBi and 51'' BV-Bi of Ridgway's Color Standards and Nomenclature. Certain weathered specimens show a more lavender tint. No accurate analysis was attempted to determine the percentage of dumortierite in the richest rock. However, its specific gravity, as determined by a Jolly Balance, is about 2.73, which, neglecting minor accessory minerals, would fit a composition of 11.11 per cent dumortierite and 88.89 per cent quartz, if the gravity of the quartz be taken at 2.66 and of the dumortierite at 3.30. Microscopic examination shows this blue rock to consist primarily of allotriomorphic crystals of quartz, from 0.1 to 0.75 mm. in diameter, cut by a few quartz veinlets of larger grain. A slight parallel flattening of the crystals, accompanied by wavy extinction, renders the rock faintly schistose. Hematite, rutile, and leucoxene are present in minor amounts. Numerous hair-like fibers of dumortierite, with maximum length of about 0.5 mm. and width of a few microns, penetrate the quartz in every direction. These fibers form felt-like aggregates, such as shown in Figure 1, that give the rock great toughness. A relatively small number of prismatic forms, with maximum observed length of 1.5 mm., width of about 0.15 mm., and strong pleochroism, occur diverging in random directions.

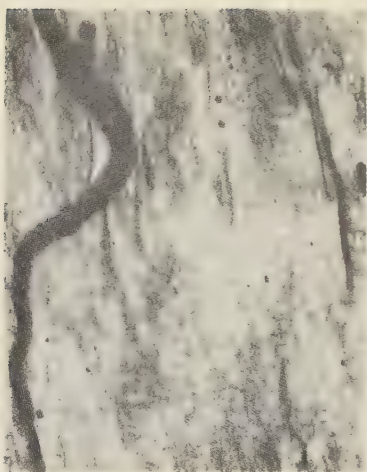


FIG. 1

View perpendicular to schistosity, showing larger curved veinlet, smaller veinlets, and fibers of dumortierite. Dark spots are rutile. One nicol. $\times 41$.



FIG. 2

Different portion of same slide as Fig. 1, but showing muscovite (M), surrounded by veinlet of dumortierite fibers, in allotriomorphic quartz penetrated by fine fibers of dumortierite. Crossed nicols. $\times 41$.

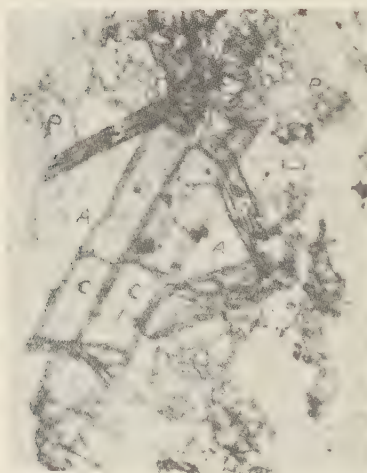


FIG. 3

Andalusite (A), cyanite (c), sillimanite (S), and pyrophyllite (P). Crossed nicols. $\times 17$.



FIG. 4

Sillimanite (S), veinlet of dumortierite fibers (D), and cyanite (C), altering to pyrophyllite (P). Crossed nicols. $\times 41$.

Veinlets of the dumortierite, which vary somewhat in character, traverse areas where these disseminations are thickest and areas where they are absent. In places, aggregates of divergent fibers follow certain bands of schistosity in vein-like fashion, with indefinite walls from 0.1 mm. to 1.5 mm. apart, but generally terminate in brushes. More commonly, the veinlets, either of fibers or of prisms, have rather definite walls that appear to mark surfaces of parting along schistosity and walls of cracks transverse to schistosity. Their maximum widths are 1–2 mm., their forms are sinuous, crenulated, forked, or sharply bent, and, if fibrous, their terminations in many places are brushes, so that when viewed with a low-power objective they resemble wisps of dark-blue smoke. Where in a matrix of coarsely crystalline cyanite, andalusite, and sillimanite, the veinlets more commonly follow boundaries between crystals, but in places cut across them. Veinlets of prisms are less abundant than veinlets of fibers, but resemble them in form and habit of occurrence. The prisms, which attain maximum lengths of 1.25 mm. and widths of 0.2 mm., generally have parallel, but in places net-like, arrangement. These veinlets usually have numerous short interruptions in their continuity.

The dumortierite, where in a gangue of cyanite, andalusite, and sillimanite, has undergone some alteration to pyrophyllite.

Quartz. The original quartz of the schist appears in thin section as a mosaic of small, allotriomorphic crystals with wavy extinction. Such cracks as traversed it are now filled with veinlets of dumortierite, later quartz, cyanite, and pyrophyllite.

The later quartz generally does not show wavy extinction. It shows penetration by the dumortierite fibers only to a slight extent and mainly around its boundaries, contains inclusions of muscovite and magnetite (?) dust, and probably is earlier than the aluminum silicates.

Certain ragged cavities in the andalusite, sillimanite, and cyanite are filled by aggregates of pyrophyllite and of quartz that probably is secondary and later than the aluminum silicates. This quartz is very irregular in outline and in places is crowded with parallel inclusions of probable pyrophyllite, together with some finely divided magnetite (?).

Cyanite (Al_2SiO_5). The cyanite occurs as bladed crystals of a color that lies between the Bremen Blue (43' GBb) and Cendre Blue (43GBb) of Ridgway's Color Standards and Nomenclature.

They commonly range in size from 0.5 mm. by 1 mm. to 1.25 mm. by 7 mm., and, in vein quartz, are as much as 10 mm. by 30 mm. Twinned forms are common. Optically, the mineral shows the normal properties of cyanite. It is definitely earlier than the sillimanite and dumortierite, and shows strong alteration to pyrophyllite and quartz. The cyanite, associated most abundantly with andalusite and relatively less abundantly with sillimanite, quartz, dumortierite, and the other minerals of the deposit, forms friable bands and bunches a few inches wide.

Andalusite (Al_2SiO_5). The andalusite occurs as rough prisms, gray to pinkish gray in color, that commonly range in size from 1 by 2 mm. to 3 by 5 mm. Prismatic cleavage at right angles and a few nearly square cross sections are evident. The mineral has the following properties of andalusite: Parallel extinction, negative sign and elongation, large optic angle, moderately high relief, medium birefringence, and crimson pleochroism along cracks in the direction of X. In addition, its indices of refraction, as determined by immersion liquids that were standardized on an Abbé refractometer, are: $\alpha=1.631$, $\beta=1.637$, $\gamma=1.642$. Although these values may be a few points in error in the third decimal place, they fit the known indices of andalusite. It is infusible and insoluble, and gives a blowpipe reaction for alumina.

The andalusite is earlier than the sillimanite, but may be later than the cyanite. It carries inclusions of pyrophyllite, rutile, finely divided magnetite, and leucoxene, and alters readily to pyrophyllite and quartz.

Sillimanite (Al_2SiO_5). The sillimanite occurs as slender, roughly terminated prisms that commonly are about 0.3 mm. wide and 1.5 to 3 mm. long. Megascopically, the mineral is not readily identifiable, but, optically, it has the normal properties of sillimanite. It is later than the cyanite and the andalusite but carries similar inclusions. Alteration has affected this mineral less strongly than it has the cyanite and andalusite, but has developed pyrophyllite and quartz. A very thin film of a dull-gray alteration product (leucoxene (?)) generally surrounds the outer borders and accentuates the relief of the sillimanite, but does not appear to have been derived from it.

In this deposit, sillimanite appears to be only one-sixth or one-tenth as abundant as andalusite and cyanite.

Pyrophyllite ($\text{H}_2\text{Al}_2\text{Si}_4\text{O}_{12}$). Pyrophyllite, in compact aggregates,

is the principal constituent of certain members of the schist. As small, micaceous flakes, it is abundantly disseminated throughout certain portions of the deposit. As radiating fibers, 2 cm. in maximum length, it occurs in thin seams along fractures, principally within the andalusite-cyanite-sillimanite aggregates. Such seams generally grade into irregular bunches that clearly were formed through alteration of the minerals of these aggregates. Any dumortierite originally present in such areas also has partially gone over to pyrophyllite.

Muscovite. Muscovite, although not abundant in the deposit, has two observed forms of occurrence.

One form, which occurs in the quartz-mica schist, is that of long shreds which are parallel to the schistosity and probably are contemporaneous with the schist. The dumortierite penetrates these shreds in a few places, but more generally surrounds their outer margins.

The other form is that of inclusions within later quartz in the schist.

Iron minerals. A black, opaque iron mineral occurs, in places abundantly, as irregular bunches and interrupted veinlets along certain partings of schistosity, and as scattered, irregular grains throughout the deposit. The veinlets have a maximum width of about 2-3 mm., and the grains range in diameter from a few microns up to 1.5 mm. This mineral has a red-brown streak and, in polished surface and thin section, the appearance of hematite. It is magnetic, probably due to admixed magnetite, but the intensity varies with different specimens. Qualitative chemical tests upon it by W. A. Sloan, of the U. S. Bureau of Mines, revealed only iron oxide and traces of sulphur. This sulphur probably came from pyrite, for a small stringer of this mineral was observed within the dumortierized schist. In a few places, the hematite has altered to limonite.

Rutile. Grains of rutile, from a few microns to about 1 mm. in diameter, and with rounded to faintly crystalline outlines, are scattered thinly throughout the deposit. It appears to be penetrated by the dumortierite, and in places is associated with hematite and lucoxene. Well-formed, clove-brown crystals of rutile, several millimeters in maximum diameter, are scattered along fractures through the vein quartz.

Sapphirine (?). Irregular grains, not over 0.75 mm. in diameter,

of a pale blue mineral occur sparingly in the dumortierized schist and the pyrophyllite schist. Although positive identification of the mineral could not be made, it has the following properties of sapphirine ($\text{Mg}_5\text{Al}_{12}\text{Si}_2\text{O}_{27}$): High refraction, low birefringence, biaxial character, and sky-blue, blue-green, and colorless pleochroism. No cleavage or twinning are visible.

Principal unknown minerals. (a) An unknown mineral occurs rather abundantly in an aggregate of fine-grained, allotriomorphic quartz and scaly pyrophyllite, cut by small prisms and veinlets of dumortierite. It is in the form of small, colorless, apparently tetragonal prisms whose nearly square cross sections show good diagonal cleavage. Optically, it has high refraction, rather strong birefringence, parallel extinction, and uniaxial positive character.

(b) An unknown mineral occurs sparingly along fractures and occupying vugs in the dumortierized schist. It is in both amorphous and elastic, fibrous forms of peach-red to pink color. Bead tests for cobalt, manganese, and iron were negative, and not enough material was available for further qualitative analysis.

(c) Assays made upon the dumortierized rock by Prof. J. B. Cunningham, of the University of Arizona, showed traces of gold. Possibly this gold accompanies one or more of the iron minerals.

ORIGIN

Probably a granitic magma invaded the schists at considerable depth and permeated favorable portions of them with hot, pegmatitic emanations that were high in silica and alumina but contained also some boron, iron, and titanium. The distribution of the resultant minerals, which appear to have replaced metasomatically the schist, indicates these emanations to have been very fluid and possibly under great pressure. Microscopic study indicates the following sequence of deposition for the principal minerals: vein quartz; cyanite and andalusite; sillimanite; rutile and primary iron minerals; dumortierite; latest quartz and pyrophyllite. Probably these minerals were deposited at temperatures below $575^\circ\text{C}.$, within the range given by Wright and Larsen⁶ for vein and geode quartz.

The temperature and pressure probably dropped considerably before the development of the pyrophyllite, for this mineral commonly forms under moderate conditions of temperature and pres-

⁶ *Am. Jour. Sci.*, 4th ser., vol. 27, pp. 446-447. 1909.

sure. As already pointed out, a large part, at least, of the pyrophyllite was developed through alteration of the anhydrous aluminum silicates. Such a reaction appears to be relatively simple and to require merely the introduction of silica and water: Andalusite, cyanite,
or sillimanite

Pyrophyllite



The possibility of pyrophyllite being derived from andalusite has been suggested by Knopf⁷ but, so far as the writer is aware, pyrophyllitization of cyanite and sillimanite has not previously been described.

ACKNOWLEDGMENTS

Acknowledgments are due the Department of Geology at the University of Arizona for the use of certain laboratory equipment. Professors F. N. Guild, B. S. Butler, and R. J. Leonard gave valuable suggestions. Mr. Robt. E. S. Heineman, of the Arizona Bureau of Mines, made the photomicrographs and many chemical tests.

⁷ *U. S. Geol. Survey, Bull.* **762**, p. 19, 1924.

NOTES AND NEWS

OCCURRENCE OF DOUBLY TERMINATED QUARTZ CRYSTALS IN SANDSTONE IN THE SHENANDOAH VALLEY, VIRGINIA

CHARLES R. L. ODER, *University, Virginia.*

The writer during the summer of 1928, while engaged in field work for his master's thesis, encountered an occurrence of doubly terminated quartz crystals similar to those described by Tarr,¹ but in this case they are replacing dolomite rather than gypsum. These crystals were found in a ferruginous sandstone of the Jonesboro formation three-fourths of a mile west of Elkton, Virginia. A like occurrence in the same formation had been noted by Mr. Charles Butts of the United States Geological Survey during the previous summer in the vicinity of Wytheville, Virginia. He submitted specimens of that material to Dr. A. A. Pegau of the Geological Department at the University of Virginia. The latter referred these specimens to the author, with the suggestion that he make a detailed study of their occurrence.

The material upon which this investigation was conducted consisted of seven specimens of ferruginous sandstone in which the quartz crystals were embedded in a matrix of brown to reddish brown iron hydroxide, collected from the two localities mentioned. This sandstone is present as bands, not over ten inches thick, at the base of the Jonesboro (Ozarkian) formation, along the upper contact of the Elbrook (Upper Cambrian) formation. It is also found at intervals throughout the Jonesboro bed, from top to bottom.

The sandstone is fine-grained to compact, thinly laminated (see Fig. 1), brownish-yellow to gray in color, depending upon the amount of dolomite with which it is mixed.

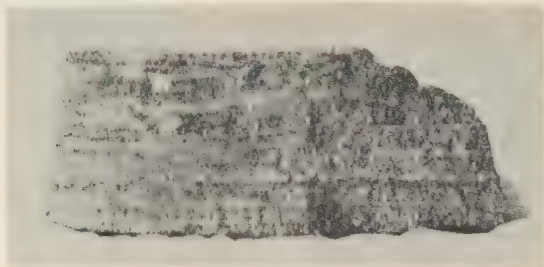


FIG. 1

Thinly laminated sandstone from the Jonesboro formation, made up of doubly terminated quartz crystals. Natural size.

¹ Tarr, W. A., Doubly Terminated Quartz Crystals Occurring in Gypsum, *Amer. Mineralogist*, Vol. 14, pp. 19-25, 1929.

The quartz crystals (see Fig. 2), ranging in length from 0.50 to 1.20 mm. and in diameter from 0.20 to .50 mm. occur in clusters and as isolated grains. In the clusters a few of the smaller crystals were found intergrown with the larger ones, but usually they are present as separate individuals. In the cases of intergrowth the crystal faces exhibit indentations which result from the separation of crystals in crushing.

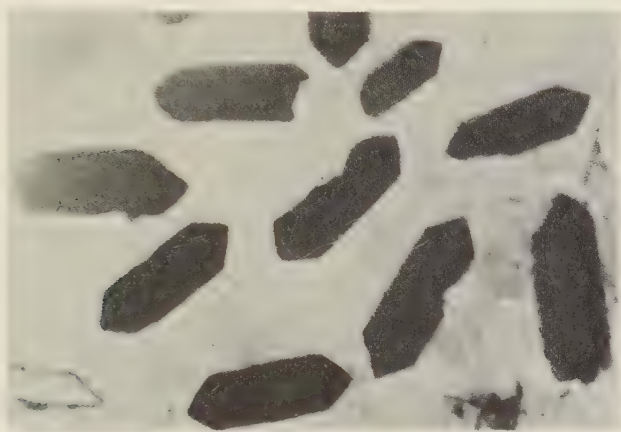


FIG. 2

Photomicrograph of doubly terminated quartz crystals from the sandstone member of the Jonesboro formation. Magnified 25 times.

The crystals usually display simple forms, hexagonal prisms, terminated by the plus (π) and minus rhombohedrons (π), equally developed. The only distortions observed were those resulting from the intergrowths of crystals in clusters.

The color results from hydrous iron oxide, originally dissolved in the silica gel in a ferrous condition and later changed to the ferric state. It appears that the silica had been uniformly stained by the iron before crystallization of the former.

Some of the specimens show pure white crystalline calcite, associated with the quartz and iron oxide. No perfect crystals of this mineral were found but good rhombohedral faces and a distinct rhombohedral cleavage were observed. Since the calcite has not been colored by the iron it seems to be of a later crystallization than the quartz.

ORIGIN

These quartz crystals were evidently formed following the solution of dolomite by ground water, and the precipitation of quartz in its place.

The silica which formed the crystals was leached from the siliceous portions of the Jonesboro formation, 600 feet of which is composed of a very siliceous dolomite, heavily laden with chert.



FIG. 3

Doubly terminated quartz crystals from the sandstone member of the Jonesboro formation. Magnified 5 times.

The abundance, perfect development, and uniformity in shape and size of the crystals points to a full, free space for crystallization indicating not so much replacement as the occupation of space already made.

The solutions from which the silica crystallized must have encountered divalent calcium in the dolomite which induced the coagulation and precipitation of the silica.

The color of the quartz crystals came from iron hydroxide, leached from adjoining rocks, which had stained the silica gel previous to its precipitation.

SUMMARY

Quartz crystals representing a solution and re-precipitation of silica in cavities formed by the solution of dolomite in the Jonesboro formation occur near Elkton and Wytheville, Virginia. The coloring resulted from the presence of iron hydroxide in the silica gel.

Dr. Willy Bruhns, professor of Mineralogy at the Bergakademie at Clausthal died June 18 at the age of 65 years.

Dr. F. Rinne, one of the honorary life fellows of the Mineralogical Society of America has been elected to honorary membership in the Royal Society of Natural Sciences of Madrid.

As a result of investigations started in 1926 the Soviet Government has announced the discovery of rich potash salts near Solikamsh in the Ural Mountains. Mining operations were started this summer employing about 5000 men.

Pennsylvania State College is erecting a new Mineral Industries Building at a cost of over \$300,000. It will be the largest academic building on the campus. The four floors will contain a large number of laboratories, class rooms and offices to care for all instruction and research work in ceramics, geology, mineralogy, geography, oil and gas production, mining and metallurgy. It is hoped to have the building ready for use when college opens in September 1930.

BOOK REVIEWS

THE LABORATORY INVESTIGATION OF ORES. A SYMPOSIUM. ERNEST E. FAIRBANKS AND OTHERS. 262+ix pages. McGraw-Hill Book Co., New York. 1928. Price \$3.50.

This book, edited by Ernest E. Fairbanks, consists of thirteen contributions (chapters) written by twelve authors, and deals with the various laboratory methods employed at present in the investigation of ore minerals. The titles of the chapters and list of authors are as follows:

Historical review of the study of polished sections of opaque minerals. Walde-mar Lindgren.

Microscopes, their construction and use. Ernest E. Fairbanks.

Crystal analysis by means of x-rays. Wheeler P. Davey.

Practical photomicrography. R. P. Loveland and A. P. H. Trivelli.

Dielectric methods. Ernest E. Fairbanks.

Genetic significance of grain. Alfred C. Lane.

Ore-mineral sequence. R. J. Colony.

The microscopic criteria of replacement in the opaque ore minerals. W. H. Newhouse.

The textural relationships of the opaque manganese minerals. G. A. Thiel.

Geologic thermometry. N. L. Bowen.

The enrichment of silver ores. F. N. Guild.

Zonal distribution. Ernest E. Fairbanks.

Ore dressing microscopy. G. M. Schwartz.

The book contains many well chosen illustrations and readily holds the attention of the reader. The question of the evidence illustrating sequence of crystallization has quite naturally brought forth conflicting views by two of the authors. Further field and laboratory work will unquestionably throw additional light on the interpretation of marginal relations. In fact, a manuscript received from Mr. H. E. McKinstry, which will appear shortly in this Journal, records additional field evidence on this interesting question.

The chapter on Geologic Thermometry by N. L. Bowen has been reprinted by the Geophysical Laboratory of the Carnegie Institution of Washington, D. C. and issued as *Paper No. 671* of their publications.

W. F. H.

LEHRBUCH DER KRISTALLPHYSIK (MIT AUSSCHLUSS DER KRISTALLOPTIK)

WOLDEMAR VOIGT. 213 figures in the text and a Table, pages XXXVI+978, 15×22.5 cm., reprinted from the first edition of 1910 by B. G. Teubner, Leipzig and Berlin, 1928. Price 41 R. M.

This is a reprint of the first edition, printed in 1910, which has now been out of print for some time. The fundamental and exhaustive character of this work has earned for it in some quarters the name "The crystallographers bible"; its reappearance in accessible form is most welcome.

The only changes compared with the first edition are an introductory page by M. v. Laue, and a third and new appendix reprinted from a paper of Voigt of 1915. The introduction by v. Laue is an interesting comment by the one man most responsible for our present detailed knowledge of the atomic structure of crystals on the permanent value of the purely formal method of attack, involving only general considerations of thermodynamics and symmetry, characteristic of Voigt's treatment. The appendix deals with secondary effects in piezoelectric phenomena. These secondary effects are in general too complicated to yield to mathematical treatment, and in the body of the book Voigt neglected them with the pious hope that they would turn out to be too small to be measurable. In the appendix it is shown that in the special case of crystal rods of circular cross section the secondary effects may be rigorously treated mathematically, and that they are indeed small enough to be neglected in the substances whose piezoelectric constants have hitherto been determined, although there is no reason to think that we may always be as fortunate in the future.

It is much to be regretted that an index was not added to the book on this reprinting, since the lack of an index was a very serious handicap to the convenient use of the first edition; an index of the numerical results obtained experimentally for different actual crystals would have been particularly helpful.

I suppose that this book will always remain one of the monumental achievements of physics, a perfect example (except perhaps for parts of the treatment of thermo-electric effects and the transverse thermogalvano-magnetic effects) of the power and application of a very general method of attack. At the same time, I believe a word of warning is not out of place against the illusion of absolute proof that such methods sometimes convey. No general method of analysis can yield results of absolute experimental validity, but assumption is bound to creep in, in the fundamental hypotheses, if nowhere else. Two sorts of hypothesis as to the physical facts have to be made before the methods of Voigt can be applied. The first is the assumption of Neumann's law, that is, that no physical phenomenon in a crystal can have elements of symmetry which are not shown by the external crystal form. Although this is a very wide generalization from experience, there seems to be no sort of necessity in it, and indeed our detailed atomic picture indicates a basis on which the law might fail. The second assumption is that most of the crystal effects can be treated as first order effects; since there are important differences of symmetry between first and second order effects, this assumption essentially enters any conclusions drawn about the behavior of actual crystals. It follows that such a simple conclusion as, for example, that the electrical resistance of a cubic crystal is the same in all directions, can have no absolute validity, contrary to a common impression, but must ultimately be asked to stand the test of experiment.

P. W. BRIDGMAN

NEW MINERAL NAMES

Nahcolite

F. A. BANNISTER: The so-called 'thermokalite' and the existence of sodium bicarbonate as a mineral. *Mineralog. Mag.*, **22**, 53-64, 1929.

NAME: From the chemical symbols Na H C O-lite.

CHEMICAL PROPERTIES: Sodium bicarbonate NaHCO_3 . Analyses on a mixture of minerals shows that from 20% to 25% of NaHCO_3 is present.

PHYSICAL AND OPTICAL PROPERTIES: Color white. Small crystals gave an extinction angle of 20° to an edge, the direction of which is negative. Very high birefringence and the maximum refractive index is only a little less than 1.590. [Winchell: Optical Characters of Artificial Minerals (*Madison*, 1927), gives the following optical data for NaHCO_3 "Monoclinic with $a:b:c=0.765:1:0.358$; $\beta=86^\circ 41'$. Crystals prismatic with (010); perfect (101), distinct (111) and imperfect (100) cleavages. $G=2.22$. Optic plane is (010). $X \wedge c = +20^\circ$, $(-)$, $2V=75^\circ$, $\rho > v$. $N_g=1.586$, $N_m=1.500$, $N_p=1.380$; $N_g-N_p=0.206$. Colorless, white"].

OCCURRENCE: Found lining the walls of a tunnel (a cuniculi or old Roman underground conduit) near Stufe di Nerone, Baja. This locality is situated about 9 miles west of Naples in the Campi Phlegraei. Occurs intimately mixed with trona, thermonatrite and thenardite.

DISCUSSION: May be accepted as a mineral species. However, a complete optical examination accompanied by an analysis on the same material is desirable when suitable material becomes available.

J. F. SCHAIRER

Mitscherlichite

F. ZAMBONINI and G. CAROBBI: Sulla presenza, tra i prodotti dell' attuale attività del Vesuvio, del tetraclorocupriato potassico diidrato, $\text{K}_2\text{CuCl}_4 \cdot 2\text{H}_2\text{O}$. *Anal. R. Osservatorio Vesuviano*, [3], **2**, 7-9, 1925.

NAME: After the German chemist, Eilhardt Mitscherlich (1794-1863), who prepared this salt artificially (*Ann. Chim. Phys.*, **73**, 384, 1840).

CHEMICAL PROPERTIES: A hydrated double chloride, $2\text{KCl} \cdot \text{CuCl}_2 \cdot 2\text{H}_2\text{O}$. A qualitative analysis showed presence of Cu, K, Cl and H_2O and no other elements.

PHYSICAL AND OPTICAL PROPERTIES: Color greenish-blue; tetragonal, $a:c=1:0.7525$. Forms present, $a(100)$ and $o(111)$. Optically uniaxial negative, feeble pleochroism. $\text{Gr.}=2.418$ at 20°C .

OCCURRENCE: Found as minute crystals on a small stalactite of salts at Vesuvius, SSW of the crater on Sept. 13, 1920, by Professor A. Malladra. It is a secondary product of the fumarolic activity. Occurs with sylvite and metavoltine.

DISCUSSION: Agrees crystallographically, optically, chemically and in physical properties with the artificial $2\text{KCl} \cdot \text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ and may be accepted as a natural occurrence of this hydrated double chloride.

J. F. S.

Maghemite

P. A. WAGNER: Changes in the oxidation of iron in magnetite. *Econ. Geol.*, **22**, 845-6, 1927. "Oxidized magnetite" or "ferro-magnetic ferric oxide" as Sosman and Posnjak originally named it, does occur in nature. Wagner finds it in the upper part of the norite zone of the Bushveld Igneous Complex. It is a strongly magnetic form of Fe_2O_3 that, except for the color of its streak, has all the properties of ordinary

hematite. To distinguish this "ferro-magnetic ferric oxide" from hematite and magnetite Wagner suggests the name *maghemite*. "Ferro-magnetic ferric oxide" is too long and 'oxidized magnetite' is misleading, as it contains no FeO." J. F. S.

'Chromloeweite'

W. WETZEL: Die salzbildungen der Chilenischen wüste. *Chemie der Erde*, 3, 389-90, 1928.

In 1923 Wetzel referred to some minute trigonal crystals found in 'caliche' as dietzeite (*Caliche*, Vol. 4, 1923). In 1924 (Supplementary table, *Caliche*, Vol. 5, 1924) W. referred them to 'an iron sulfate' and now they are called 'chromloeweite.' Chromium was found by a microchemical test. The crystals are uniaxial negative, $\epsilon = 1.449$, $\omega = 1.496$.

DISCUSSION: The data are very unsatisfactory. Names should not be given to burden mineralogical nomenclature until more reliable data are procured.

J. F. S.

'Manganese silicate from the Hôkô Mine'

K. KINOSHITA: A manganese silicate from the Hôkô Mine, Prov. Alci. *Jour. Geol. Soc. Tokyo*, 34, 52-8, 1927 (Japanese); Abstract in *Jap. Jour. Geol. and Geogr.*, 5, No. 4, p. 19, 1927.

The mineral occurs with psilomelane and rhodochrosite forming a bedded deposit in a Palaeozoic hornstone. The mineral is subtranslucent, resinous to vitreous in luster, and is black or dark brown in color. Streak: brownish black. On exposure to the sunlight the color changes to black. Hardness: 3.5. Sp gr.: 3.354. Microscopically, it is light brown, optically isotropic, and contains fine dust of quartz. The chemical analysis of the mineral gave the result: SiO₂ 20.61, Fe₂O₃ 1.65, MnO 46.56, Mn₂O₃ 18.89, Cu 0.14, Al₂O₃ 2.09, CaO 1.07, MgO 1.63, H₂O 4.00, H₂O (110°) 5.89. This corresponds to SiO₂ · (MnO · Mn₂O₃) · H₂O.

DISCUSSION: Probably an altered rhodonite, braunite or tephroite.

J. F. S.

BODENBENDERITE

E. RIMANN: Bodenbenderite, a new mineral from Argentina. *Sitzungsber. Abhandl. Naturwiss. Gesell. Isis, Dresden*, 1928. Festschrift für Richard Baldauf, pp. 42-51.

NAME: In honor of Prof. Wilhelm Bodenbender (1857-), of Cordoba, Argentina.

CHEMICAL PROPERTIES: Analysis after deducting 16.7% impurities gave: SiO₂ 21.02, TiO₂ 8.74, Al₂O₃ 10.16, (Yt, Er)₂O₃ 15.59, MnO 40.49, CaO 2.48. Rest U₂O₃, Fe₂O₃, FeO, MgO, giving the formula 4RO · R₂O₃ · 3RO₂ or (Mn, Ca)₄ Al [(Al, Yt)O] [(Si, Ti)O₄]₃. By means of HCl the mineral was separated into a soluble and insoluble portion. The soluble component (62%) has the compn. of water-free plazolite (3RO · R₂O₃ · 2RO₂) and the insoluble component that of the triple vesuvianite molecule (6RO · R₂O₃ · 6RO₂). Bodenbenderite = plaz. 62%, vesuv. 38%.

PHYSICAL PROPERTIES: Color flesh red. Vitreous luster. $n > 1.77$. Gr. = 3.3-3.5. H. = 6-6.5. The mineral fuses to a black slaggy glass.

OCCURRENCE: Found in pneumatolytic veins near granite in the Sierra Chica, Sierra de Cordoba, Argentina, with fluorite, peninine, muscovite, helvite, garnet, beryl, epidote and vesuvianite.

DISCUSSION: Data unsatisfactory.

J. F. S.